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Low-Elevation-Angle Propagation Effects on COMSTAR Satellite Signals

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I. INTRODUCTION

Little information exists on earth-space propagation at lower elevation angles. One earlier experiment[1] has shown greater fluctuation in signal levels over low-elevation paths. This signal fluctuation likely results from focusing and defocusing by inhomogeneities in the atmosphere's index of refraction caused by turbulence. The fluctuation increases at lower elevation angles, then, because the signal must pass through more atmosphere.

The opportunity existed during 1976 to make more low-elevation observations at 19 GHz as the COMSTAR satellites were placed into position. This paper describes the acquisition and analysis of the low-elevation propagation data. Results are presented showing the fluctuation intensity of the received signal at several elevation angles.

II. EXPERIMENT

Two satellites were launched carrying 19-GHz beacon transmitters, COMSTAR I in May 1976, and COMSTAR II in June 1976. As they were placed in their final positions, they drifted upward from the horizon at a rate of 1 to 2 degrees per day. Original data were taken at 19 GHz on Crawford Hill for elevation angles from 1 to 10 degrees above the horizon with a 3.7-meter diameter antenna and an interim receiver.[2] Signals received on vertical and horizontal polarizations (relative to the Crawford Hill horizon) were recorded on analog magnetic tape.

* This work was performed while Ms. Titus was a summer student.

The satellites were rotating slowly; therefore, the directional antenna on the satellites caused the received signal level to vary. There was very little variation over a period of a few minutes, however. Weather throughout the initial experiment was generally cloudy and overcast, but there was no significant precipitation. The 0.3-degree beamwidth of the Crawford Hill antenna precluded ground-reflected signals. Since both transmitter and receiver had excellent amplitude stability, atmospheric turbulence was the only reasonable source of the signal-amplitude fluctuations observed. These fluctuations occurred almost all the time, as contrasted with the more infrequent multipath fading observed on terrestrial paths.

On the analog magnetic tape, data samples were taken once every hour for ten consecutive minutes. For each 10-minute interval (corresponding to a particular elevation angle), three sets of 256 points, sampled at a rate of 5 points per second, were digitized and recorded under control of an HP 9830 calculator. Signal amplitudes for the two polarizations were sampled simultaneously. The three 51-second samples of digitized signals were taken from the beginning of the ten-minute run unless some readily apparent problem existed on the chart data.

III. RESULTS

After data samples were digitized from all magnetic tapes, an analysis was made to determine how elevation angle affected signal fluctuation. For each sample set, the mean and standard deviation of the received signal amplitude for each polarization and the correlation coefficient between the vertically and horizontally polarized signals were calculated.

Some sample sets were unusable because of low signal levels, so a method was devised to locate and delete them. It was assumed that the receiver noise level was the same as that existing later in the experiment, when the signal-to-noise ratio was approximately 46 dB in clear air. From this assumption a graph was constructed that gave, as a function of mean receiver output in volts, the standard deviation-to-mean ratio expected from receiver noise alone. Each sample set was checked and deleted if its fluctuation was not at least two standard deviations higher than that expected from receiver noise alone.

For all remaining sample sets, scatter plots of fluctuation (defined as the ratio of the standard deviation to the mean) vs. elevation angle were printed. Figure 1 shows an example for COMSTAR I using horizontal polarization. Results for the horizontal polarization from COMSTAR II and for the vertical polarization from both satellites were also plotted, and were very similar to the results shown. Multiple data exist

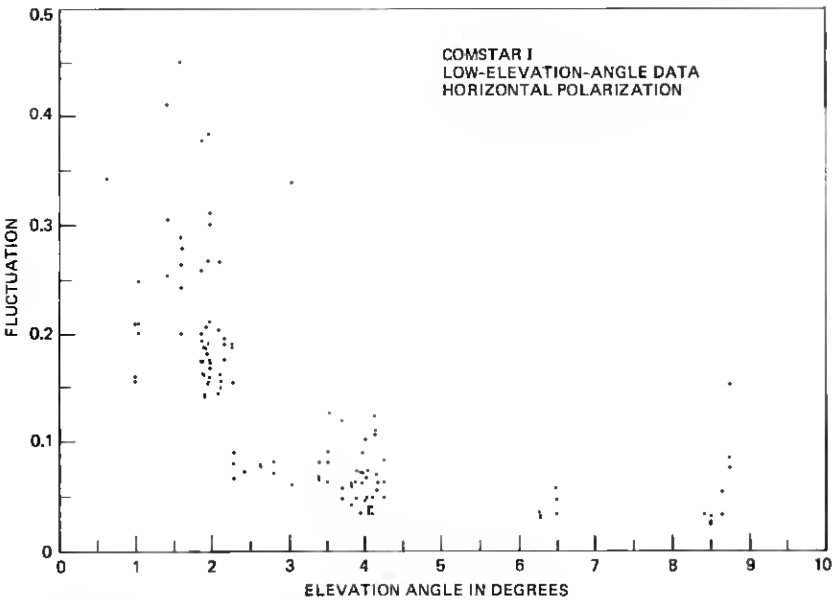

Fig. 1—19-GHz signal amplitude fluctuation vs. path elevation angle for COMSTAR I using horizontal polarization.

for certain elevation angles, because in those cases the satellites were at nearly the same elevation angles for more than one hour.

Figure 1 indicates that signal fluctuation increases dramatically as the path elevation angle decreases. A simple theory to explain this trend involves the notion that the strength of the fluctuation is dependent on the number of air masses through which the propagation path passes. The number of air masses is proportional to the integral of the density (kg/m^3) of the atmosphere along the path. One air mass is defined as the density integral along a vertical path.

The number of air masses as a function of elevation angle was calculated in two ways: (*i*) by assuming that the atmosphere can be modeled as evenly distributed over a height up to nine km, and (*ii*) by modeling the atmosphere as six layers from altitudes of 0 to 30 km with different densities.[3] The latter was done for both evenly spaced layers (steps of 5 km/layer) and unevenly spaced layers (steps of 2, 3, 5, 6, 6 and 8 km/layer) to observe the effect of the higher density of the lower atmosphere at the very low angles. The results for the two methods are compared in Fig. 2 and show no significant differences. Therefore, the simpler method was used for the following results. Both methods depart radically from the cosecant angular dependence seen

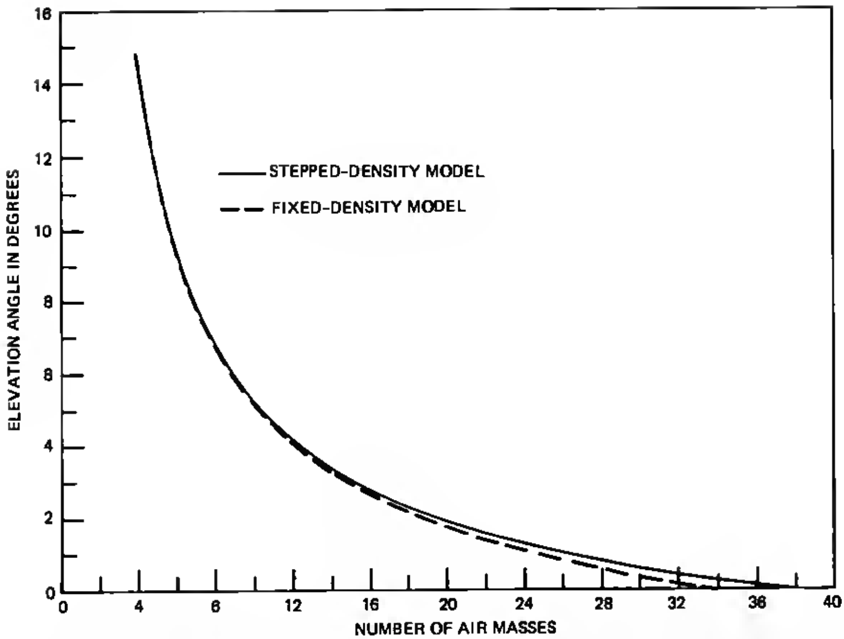

Fig. 2—Path elevation angle vs. number of air masses for stepped-density and fixed-density atmospheric models.

at higher elevation angles,[4] owing to the earth's curvature.

Figure 3 shows a scatter plot of signal fluctuation vs. number of air masses for the combined data from COMSTAR I and COMSTAR II. This figure shows that the fluctuation of the signal increases rapidly as the number of air masses increases. The functional form of this dependence cannot be determined from the available data, but appears to be at least linear. For very low-elevation-angle paths (1 to 1.25 degrees) traversing a large number of air masses (24), the signal fluctuation varies about 0.25. For a significantly smaller number of air masses (i.e., below 8), and relatively higher elevation angles (above 6.50 degrees), the fluctuation decreases to around 0.05.

Results for both received polarizations show that fluctuations with number of air masses for the two polarizations are nearly identical. Instantaneous correlation coefficients between the polarizations were typically above 0.95 when the fluctuations were also large compared with the receiver noise level (i.e., at low-elevation angles). It thus appears that the cause of the fluctuation is not dependent on the state of the polarization—vertical or horizontal. This is the first known observation of this polarization independence for elevation angles below 5 degrees.

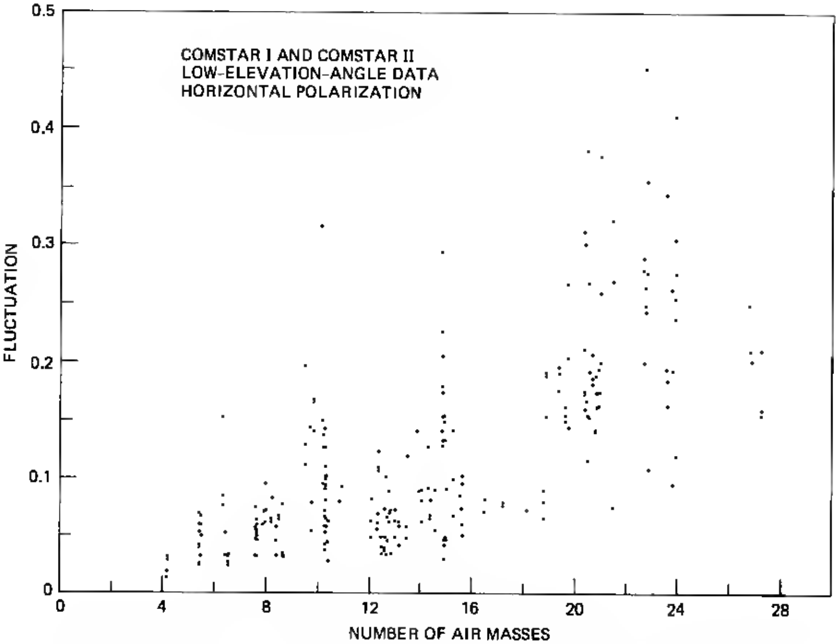

Fig. 3—19-GHz signal amplitude fluctuation vs. number of air masses along path for combined COMSTAR I and COMSTAR II data using horizontal polarization.

IV. CONCLUSIONS

Two conclusions can be drawn from this experiment. One is that the signal fluctuation is independent of polarization. Two facts lead to this conclusion: (*i*) there is a very high correlation between signal strengths at the two polarizations; and (*ii*) the results for fluctuation vs. number of air masses were nearly identical for the two polarizations. The second conclusion is that fluctuation intensity increases at lower elevation angles. This increase is consistent with the increase in the number of air masses along the path.

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